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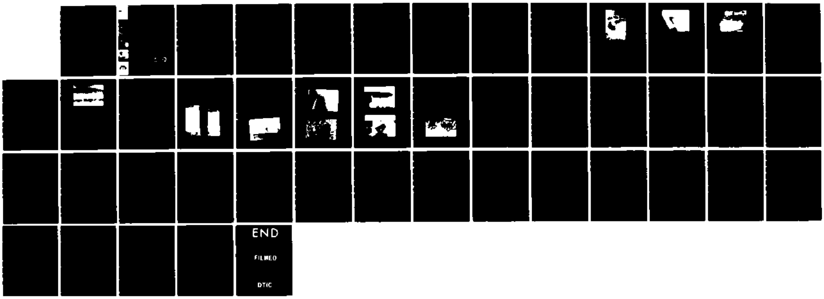

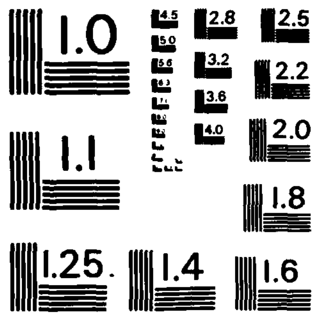

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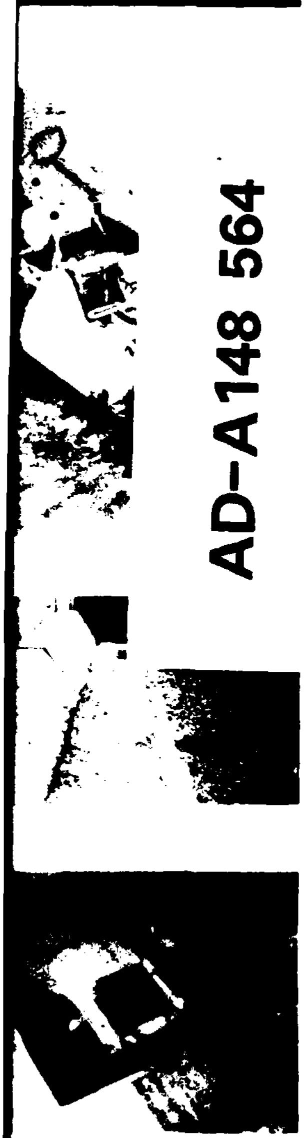

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TECHNICAL REPORT SL-84-17

NO-SLUMP ROLLER-COMPACTED CONCRETE (RCC) FOR USE IN MASS CONCRETE CONSTRUCTION

by

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Final Report

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STRUCTURES LABORATORY

20. ABSTRACT (Continued).

(c) determine methods of improving hardened lifts joints, (d) determine the relative frost resistance of RCC, (e) evaluate the erosion susceptibility, and (f) discover economical methods of obtaining void-free vertical surfaces.

Indications are that: (a) the curb concrete is a viable method of forming and containing RCC; (b) the degree of compaction achieved is dependent on the stiffness and the paste content of the mixture, the lift thickness, and the individual roller; (c) the tensile strength of the untreated joints increased with paste content and quality from approximately 25 percent for relatively lean RCC to approximately 50 percent for richer RCC; (d) erosion resistance at 35-ft/sec fluid velocity of RCC is good; (e) resistance to freezing and thawing of the RCC is poor, apparently due to a poor air void system; and (f) surface treatment with a mortar gun (shotcrete) appears to be a practical method to achieve smooth vertical surfaces.

PREFACE

The investigation reported herein was authorized by a letter dated 24 April 1975 from the Office, Chief of Engineers, U. S. Army, in response to a US Army Engineer Waterways Experiment Station (WES) letter dated 19 March 1975, subject: Project Plan for Investigation of No-Slump Roller-Compacted Concrete (CWR Work Unit 31240). The Technical Monitor for this investigation was Mr. Fred Anderson, DAEN-ECE-DC.

The investigation was conducted during the period 1975 to 1981 at the Structures Laboratory (SL), WES, under the supervision of Messrs. Bryant Mather, Chief, SL, and John M. Scanlon, Chief, Concrete Technology Division. Mr. Kenneth L. Saucier was the project leader and prepared this report.

Commanders and Directors of WES during this investigation and the preparation of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees	0.01745329	radians
feet	0.3048	metres
feet per second	0.3048	metres per second
horsepower (550 ft-lbf/sec)	745.6999	watts
inches	25.4	millimetres
pounds (force)	4.447	newtons
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	square metres
tons (2000 lb)	907.1847	kilograms

NO-SLUMP ROLLER-COMPACTED CONCRETE (RCC) FOR USE IN MASS CONCRETE CONSTRUCTION

PART I: INTRODUCTION

Background

1. The cost of concrete construction is continually rising. Recent proposals indicate that if the present conventional methods of placing mass concrete were changed, considerable savings in construction costs could be realized. The use of no-slump concrete and embankment techniques (i.e., a bulldozer to level the concrete and a vibratory roller to externally consolidate the concrete) would permit a significant cost reduction (Camellerie 1974).

2. No-slump concrete is concrete having no slump but containing the minimum amount of water necessary to achieve consolidation with a vibrating roller. It is anticipated that such a concrete mixed and placed in large volumes would result in moderate savings in cement cost and significant savings in labor cost required for consolidation of conventional mass concrete. Most promising applications appear to be for use in construction of mass sections or as a foundation or pavement slab.

3. Results of a previous investigation using earth compaction methods (15-ton* vibratory roller) have been reported by the Tennessee Valley Authority (Cannon 1972). Tests at the U. S. Army Engineer Waterways Experiment Station (WES) demonstrated the feasibility of mixing, hauling, spreading, leveling, and compacting no-slump concrete for a massive section (Tynes 1973). Additional studies indicated that the RCC technique could be adapted to certain types of paving construction (Burns 1976). Results of tests on drilled core specimens indicated that the unit weight and strength properties of the concrete were the equal of conventionally placed concrete.

4. Studies by Hall and Houghton (1974) at the Lost Creek Dam site proved the practicality of application of RCC to a mass concrete project. The first full-scale use of RCC in mass concrete construction in the United States

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

occurred with the completion of Willow Creek Dam in Oregon in 1982 (U. S. Army Engineer District, Walla Walla, 1983).

Purpose

5. The objective of the investigation reported herein was to study the problems associated with the use of no-slump RCC for mass concrete construction and investigate possible solutions for problems encountered.

Scope

6. Tests were conducted to: (a) optimize mixtures for application of no-slump techniques, (b) develop a consistency and quality control technique, (c) determine methods of improving hardened lift joints, (d) determine the relative frost resistance of RCC, (e) evaluate the erosion susceptibility, and (f) discover economical methods of obtaining void-free vertical surfaces.

PART II: MATERIALS, EQUIPMENT, AND TESTS

Materials

Portland cement

7. A Type II portland cement (RC-705) from Alabama was used in all mixtures; the chemical and physical properties of the cement are presented in Table 1.

Fly ash

8. A fly ash meeting the requirements of CRD-C 255 (ASTM C 618) (U. S. Army Engineer Waterways Experiment Station 1949) for Class F was used in several mixtures. The chemical and physical properties of fly ash are given in Table 2.

Aggregates

9. The limestone fine (CRD MS-27) and coarse (CL-2 G-1) aggregates were obtained from Alabama. The natural fine and coarse aggregates were obtained locally. The physical properties and gradings of the aggregates used for specific mixtures are given in Tables 3-6.

Equipment

Vibratory roller

10. A small self-propelled, dual-drum vibratory roller (Figure 1) was used to compact small test sections for study. The purpose in using a relatively small roller was to (a) allow work to be conducted on a laboratory scale and (b) determine if a small roller would facilitate compaction around obstacles and boundaries. Pertinent information on the roller follows:

Length, in. (mm)	76	(1,930)
Height, in. (mm)	35	(890)
Width, in. (mm)	33	(840)
Drum width, in. (mm)	27	(690)
Drum diameter, in. (mm)	16	(400)
Static mass, lbm (kg)	1212	(550)
Vibrations per minute	3300	
Dynamic force, lbf (N)	4400	(19,570)
Power unit; diesel, hp (W)	7.0	(5,220)

Vibrating table

11. A vibrating table was used in the tests to control the consistency

Figure 1. Vibratory roller used
for compacting RCC

of the RCC. The table had a frequency of 3600 Hz and was operated at an amplitude of 0.015 in. (0.38 mm) during this study.

Erosion apparatus

12. An apparatus was constructed for this investigation to determine the amount of erosion of RCC due to the impingement of high velocity water. The apparatus was designed so that a jet of water (approximately 1 by 8 in.) having a velocity of 40 ft/sec would impinge on the specimen surface at an angle of 5 deg from the horizontal. The center of the specimen was placed 12 in. from the source of the water jet. The specimen was examined at intervals to note any deterioration of the surface. The intervals were every 1/2-hr up to 1-hr testing, every 1-hr up to a total of 4-hr testing, and, finally, every 4 hr up to termination of the test. The test specimens were 12 by 12 by 1 in. thick. A specimen under test is shown in Figure 2.

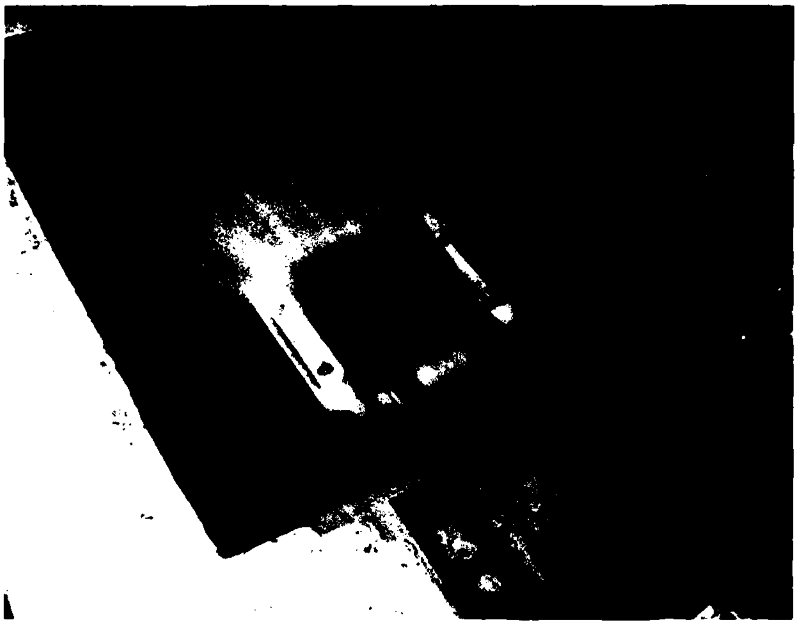


Figure 2. Erosion test apparatus

Mortar gun

13. A small mortar gun which pneumatically applies a shotcrete mixture to a rigid surface was used as a surface treatment technique for the rough edges of RCC. The gun, developed at the Missouri River Division Laboratory, is shown in Figure 3 (Coy 1974).

Mechanical compactor

14. A large mechanical compactor normally used to define moisture-density curves for gravel-sand mixtures was used to study the compaction characteristics of two RCC mixtures (Donaghe and Townsend 1975). For these tests a 10-lb hammer compacted the material in a 6-in.-diam mold.

Tests

Mixtures

15. Work by Leflaire and Morel (1975) indicated that RCC mixtures must be optimized for the particular roller to be used. Mixtures were therefore proportioned to accommodate the smaller roller and to determine if more fluid or smaller-nominal-maximum-size-aggregate mixtures could be consolidated near rigid boundaries. Information on the individual mixtures is given in Table 7.

Figure 3. Mortar gun and applications

Summary information on all mixtures is given in Table 8. The excess paste was that portion of the water and cementitious material (portland cement and fly ash) in excess of that required to fill all voids in the fine aggregate.

Quality control

16. The consistency and quality control technique used in this investigation was essentially that used by Cannon (1972). A sample of material was placed in a 0.25-cu-ft (0.007 cu m) container, struck off level with the top of the container, and vibrated until consolidation occurred. The time of vibration was recorded as consolidation time. The test result is, of course, subject to the judgment of the operator. The same operator conducted the tests throughout this program, and results appeared to be consistent.

Tensile strength of joints

17. A point-load tensile test was used to evaluate the strength of the lift joints. The tensile strength is determined by applying compressive point-loads to the curved surface of a cylindrical core specimen with the axis of the core horizontal (Reichmuth 1963). The point-loads are applied by a testing machine through small-diameter, hardened steel rollers at right angles to the axis of the specimen. This loading produces tensile stresses perpendicular to the axis of loading; the tensile strength σ_t is given by an empirical

expression

$$\sigma_t = \frac{0.96P}{D^2}$$

where

P = failure load, lb

D = core diameter in.

The test configuration is shown in Figure 4.

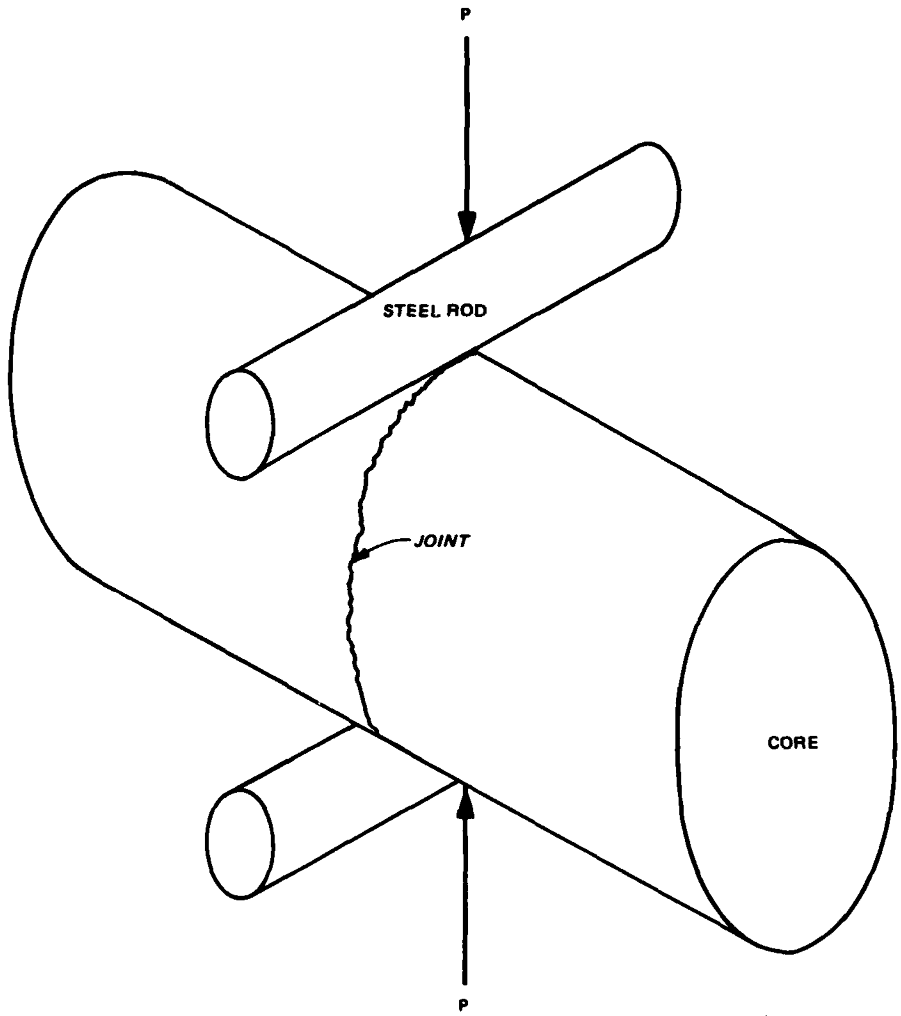
Curb concept

18. Preliminary work indicated that even relatively wet RCC would not consolidate against a vertical boundary (Figure 5). The curb concept for containment of RCC was therefore investigated in a small-scale field experiment. The basic idea consists of extruding high quality rapid setting concrete from a forming machine to the shape required for construction of the curbs. After one day the concrete should attain a compressive strength of 2000 to 3000 psi (14 to 20 MPa), thus being able to withstand the pressures of the vibratory roller used to compact the RCC.

19. The study plan is given in Figure 6. The curb concept is considered attractive since the sloping sides of the curbs allow the vibratory roller to force the RCC down into the hardened curb concrete, thus reducing the large number of voids which usually occur when compaction is effected against a vertical boundary. The small, dual-drum, 1200-lb (550-kg) roller was used in the work described herein. An extrusion apparatus was not available for fabricating the curbs; therefore, the curbs were formed and cast by conventional methods. The curb concrete contained 600 lb (270 kg) of portland cement per cubic yard and had a slump of 1.5 in. (38 mm); this mixture achieved a strength of 3000 psi (20 MPa) at one-day age. The curbs were cured overnight and stripped immediately prior to placement of the no-slump rolled concrete; this usually occurred when the curb concrete was about 24 hr old. On one occasion the sloping face of the curb was removed soon after initial set and the face scarified to improve bond.

Resistance to freezing and thawing

20. Resistance of RCC to freezing and thawing was investigated in the laboratory. Laboratory specimens were cast and tested according to American Society for Testing and Materials (1983), C 666-80, Procedure A. Some of the tests were not started until the specimens were 90 days old.



NOTE: TEST OF PARENT CONCRETE CONDUCTED WITH IDENTICAL CONFIGURATION.

WHERE: $T = 0.96P/D^2$

T = TENSILE STRENGTH, PSI

P = FAILURE LOAD, LB

D = CORE DIAMETER, IN

Figure 4. Point-load tensile test

Figure 5. RCC compacted against a vertical surface (three lifts)

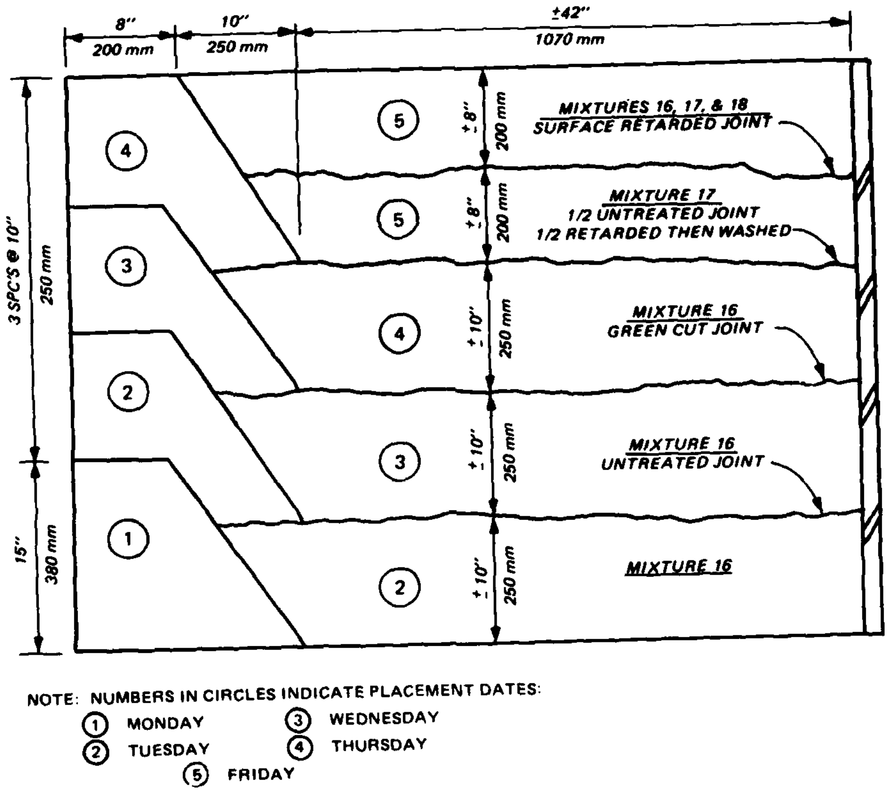


Figure 6. Curb study

PART III: RESULTS

Mixture Proportioning

21. Due to its successful application in the work reported by Tynes (1973), mixture 1 was used as a starting point. It was discovered that the relatively dry (consolidation time of 90 sec), large aggregate (3 in., 75-mm) mixture could not be effectively consolidated by the small roller. Since a lift thickness of 10 in. (250 mm) was needed due to the rock size, the water content of the concrete was increased (mixture 6). A consolidation time of 20 sec produced concrete that was a little wet; a consolidation time of 30 to 40 sec appeared to produce a concrete of the consistency required in order to achieve good consolidation under the roller. Consolidation times of less than 20 sec (mixture 13) resulted in segregation problems. Mixtures 7 and 8 were made to investigate changes in aggregate fractions which might improve consolidation of 3-in. material. Ten percent smaller rocks (mixture 8) proved beneficial. Use of natural coarse aggregates (mixture 14) resulted in an exceptionally smooth rolled surface not observed with crushed aggregates. However, it was concluded that the small roller would not prove feasible for extended rolling of 3-in. (75-mm) nominal maximum size aggregate concrete. Also, in actual practice smaller aggregate concrete would normally be used near obstacles and boundaries. Consequently, most of the remainder of the test program was devoted to the techniques of working with nominal 1.5-in. (37.5-mm) or smaller maximum size aggregate concrete.

22. The work with mixture 2 indicated that the roller would consolidate relatively dry small aggregate concrete but only in lifts of approximately 4 in. (100 mm). Since 4-in. lifts would not likely prove practical, it was decided to try incremental lift depths up to 10 in. The 10-in. lifts at a consolidation time of 60 sec were not satisfactory (mixture 4), but were satisfactory at a consolidation time of 45 sec when placed over relatively fresh concrete. A consolidation time of 25 to 35 sec proved to be the optimum (mixtures 9 and 11) for concrete placed on rigid, hardened surfaces. Mixture 12A was a modification of a conventional RCC mixture to achieve 7 percent total air. The rolling of mixture 12A was satisfactory, but there was no practical way to determine how much of the total air was entrained air. Mixture 15 was proportioned to represent a paving mixture reported by Burns (1976), and the

rolling and consolidating of this mixture were satisfactory.

23. The tests with mixtures 16 and 17 proved to be very significant. During the curb tests a board was wedged between the curbs to provide a continuous curb section. Immediately after the lifts were rolled, the board was removed to observe the effect of consolidation in the underside of the compacted concrete. Figure 7 shows the undersides of mixtures 16 and 17. Note the improved degree of consolidation with mixture 17, which had 5 percent excess paste compared with only 2 percent for mixture 16. It was concluded that the excess paste was the significant factor in the compaction process. However, when the paste content became relatively large (8 percent in mixture 18), the mixture became sticky. Mixture 10 with natural aggregates had a springy

a. Mixture 16

b. Mixture 17

Figure 7. Underside of compacted mixtures 16 and 17

effect and yielded a very smooth surface similar to mixture 14 under the rolling action.

24. All three RCC mixtures used in the curb trials were proportioned to have a consolidation test time of 20 to 25 sec. Thus, all were relatively wet by no-slump concrete standards. Three double passes were used in compacting all lifts. Mixture 16, the basic mixture, was used for the first three lifts. Mixtures 17 (lift 4) and 18 (portion of lift 5) were proportioned to have increased paste contents. Observations indicated that (a) all mixtures rolled satisfactorily and (b) the curb concept appeared to be a viable method of forming and containing RCC (Figures 8-11).

25. The concrete curbs were cast in two sections (Figure 12). The resulting space between the adjacent curb sections was closed prior to RCC placement by wedging a board in line with the sloping curb surfaces. The board was removed after compaction and the degree of consolidation was observed. Although the mixtures appeared to be fully consolidated, the underside of the compacted concrete revealed differences in the mixtures. Some minor alignment problems developed with the formed curbs; however, a properly operated extrusion machine designed especially for the curb section should rectify these problems.

Figure 8. One 16-cu-ft batch of mixture 1

Figure 9. Complete lift of mixture 1

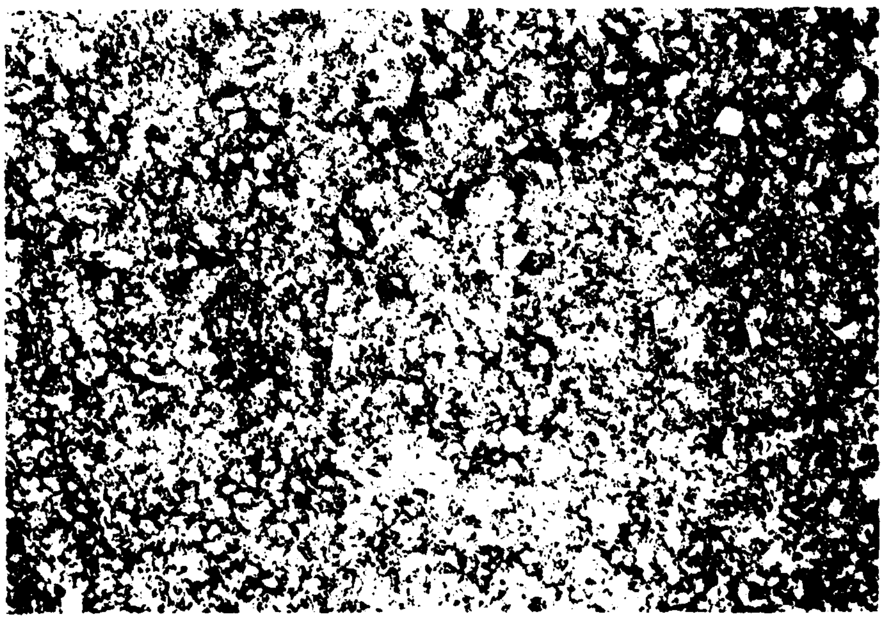


Figure 10. Compacted top surface of mixture 2

Figure 11. Completed curb trial section

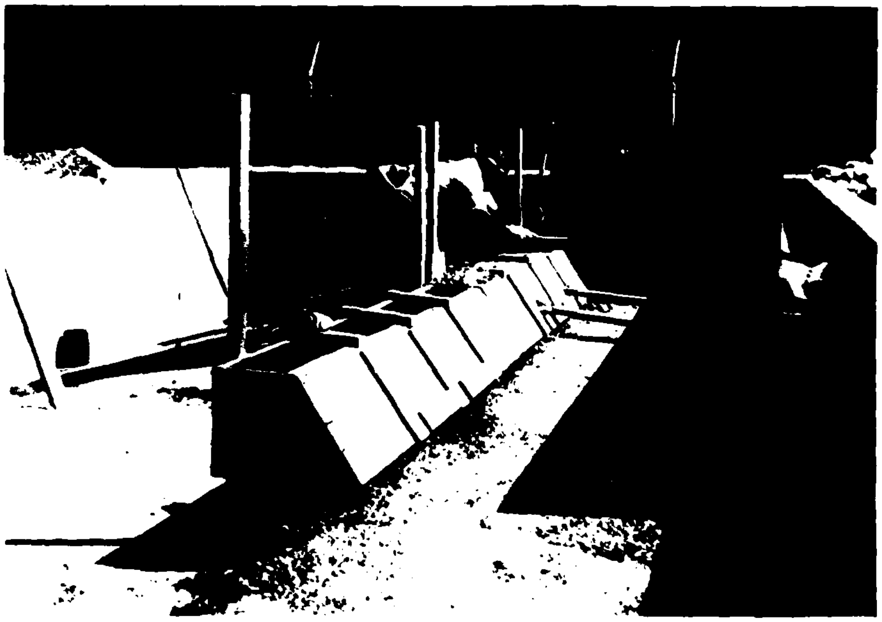


Figure 12. Forming and casting of curbs

26. The test section was cored when the concrete reached 90 days age. Twelve 6-in. (152-mm) cores were taken as follows: (a) four vertical cores full depth through the RCC, (b) four vertical cores at the interface of the RCC and the curbs, and (c) four horizontal cores at the RCC joints. Intact joints were present only on the untreated joint and the retarded-then washed joint of mixture 17 of the RCC. Good mechanical interlock was evident at all other RCC joint surfaces; however, the core separated at the joints when removed from the hole. It was expected that good bond would develop at the top lift under mixtures 17 and 18, but such did not happen. The four cores drilled horizontally through the joints verified the findings of the vertical cores, namely that the joints were intact in two cores drilled at the interface of mixture 17 (placement day 7), but only mechanical interlock on the other joints was observed.

27. The four vertical cores drilled at the interface of the RCC and the curbs revealed (a) excellent adhesion between the curbs and (b) relatively good bond of the RCC to the curbs. The 6-in.- (152-mm-) diam cores included only feather edges of the RCC; thus many of the edges broke during removal from the core hole. Good bond was evident in many cases, where the RCC exceeded the 2-in. (50-mm) depth, and especially on the scarified curb (Figure 13).

Figure 13. Scarified face on one curb section

Tests of Fresh Joints

28. Examination of specimens taken from concrete produced during the mixture proportioning studies revealed that very poor bond developed between lifts of mixtures which were very dry or contained relatively low amounts of cementitious material. In order to investigate the bonding characteristics of RCC, three 6-in. (150-mm) lifts of mixture 9 were rolled and cores were taken and tested for tensile strength at 90 days age by the point-load test proposed by Reichmuth (1963) (Figure 4). Results are given in Table 9. The fresh joint (1-hr age) strength is almost the equal of the parent concrete. However, the cold joint developed a strength of only about half that of the base material. Apparently if the concrete is consolidated before time of initial setting, the material acts almost as a uniform mass; however, after time of final setting is reached in the lower lift, complete bond between lifts will not be achieved.

Tests of Cold Joints

29. In order to determine if the intact joints achieved with mixture 17 were due to the increased paste content or the reduced lift height, a supplemental test section was rolled (Figure 14). A 3-in. (75-mm) lift of mixture 16 provided the base for placement of three 6-in. (150-mm) lifts, one each of mixtures 16 and 18, and half sections of mixtures 19 and 20. Mixture 19 with a slump of 1 in. (25 mm) and mixture 20 with a slump of 8 in. (200 mm) were used to provide a basis for evaluating the bond of the RCC concrete. Mixture 19 was vibrated; mixture 20 was essentially flowing concrete. All joints were untreated except for wetting prior to concrete placement. Twelve vertical concrete cores were drilled through the section for testing.

30. The tensile strengths of the cold joints and the parent concrete were determined at 90 days age. Results of the tensile tests are given in Table 10. Mixture 19, the control mixture, developed 305-psi (2100-kPa) tensile strength in the concrete and 223 psi (1550 kPa) or 74 percent in the joints. Mixture 16 developed 225 psi (1550 kPa) in the concrete and only 60 psi (410 kPa) or 27 percent in the joint. Significantly, only 7 of the 12 joint cores were recovered from mixture 16. Mixture 18 had cement content and water-cement ratio identical with those of mixture 19 and developed almost

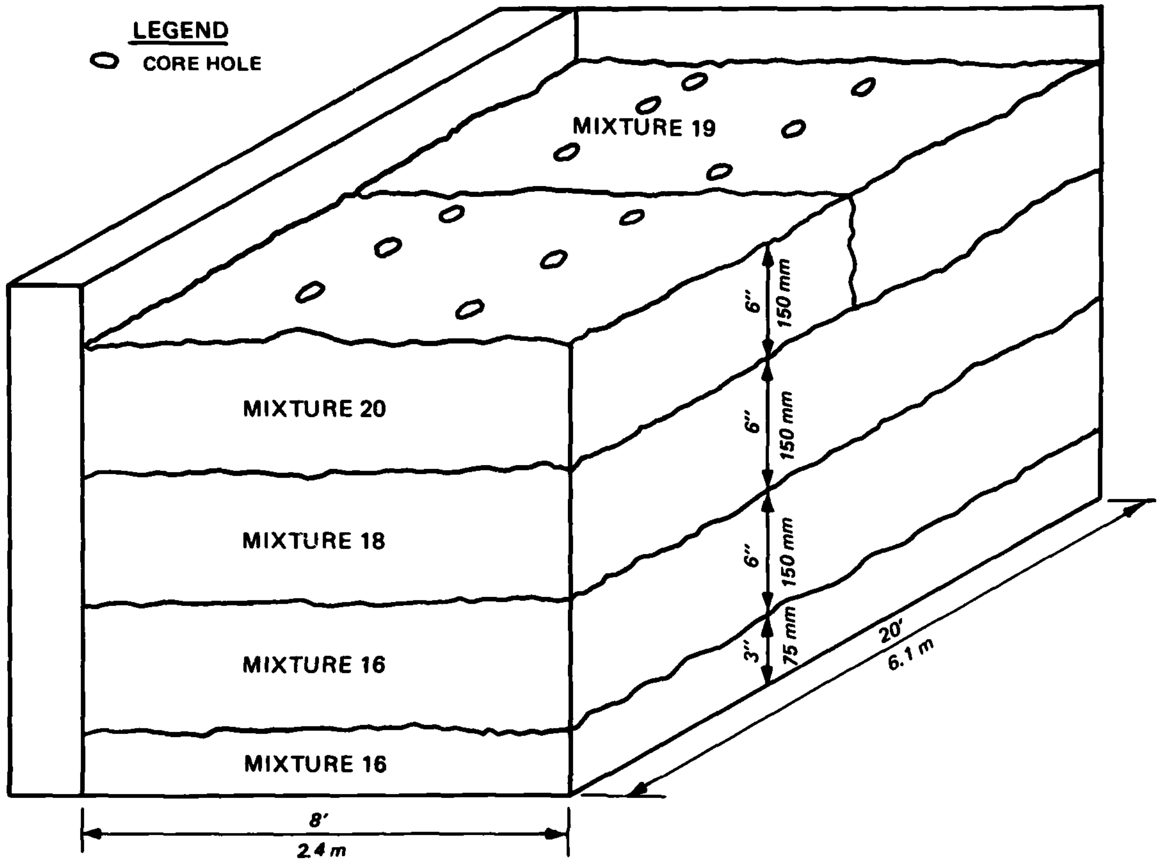


Figure 14. Supplemental study

as much strength in the matrix. Thus, it appeared that good consolidation was achieved with the roller on mixture 18. An average joint strength of 44 percent of the concrete strength was obtained on 11 out of 12 possible core tests. This compares with 50 percent joint strength achieved previously on mixture 9. Mixture 20, the high-range water-reducing admixture, developed less strength than mixture 19, although mixture proportions were identical. Significant segregation which was obtained when using mixture 20 may have caused the lower strengths.

Moisture-Density Relationships

31. In order to gain some measure of the relative amount of water being used in the RCC mixtures in relation to the compaction curves developed for conventional earth compaction procedures, moisture-density relationships were

determined for two mixtures, 12 and 15. The results, given in Figures 15 and 16, indicate that the optimum water content (to secure maximum density) is approximately 5 percent for these mixtures. By comparison, the water contents used for these mixtures, as determined from Table 8, to secure compaction with the vibratory roller were 3.7 percent and 4.1 percent, respectively. Therefore, indications are that the vibratory roller must operate on RCC mixtures which have approximately 1 percent less moisture than optimum to prevent sinking of the roller into the mass.

Erosion Tests

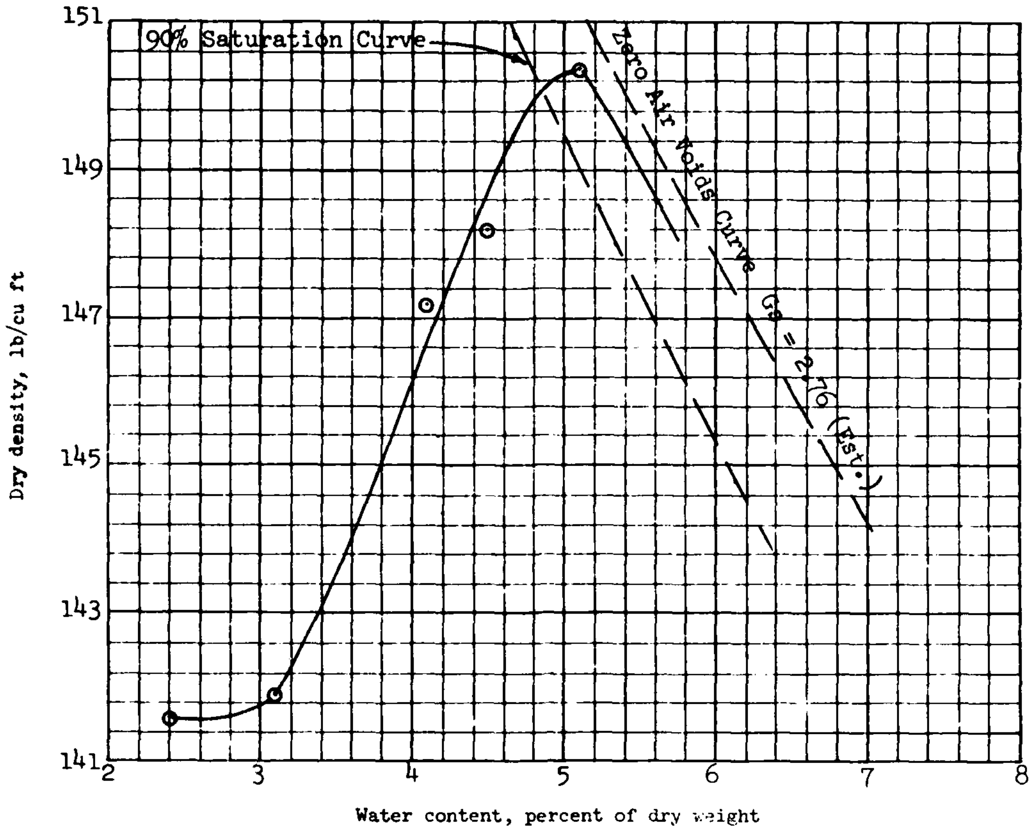
32. Tests of erosion resistance of RCC were conducted on two specimens received from the U. S. Army Engineer Division Laboratory, North Pacific, and two specimens fabricated at WES from mixture 6. The specimens were examined at intervals to note any deterioration of the surface. The impinging jet is shown in Figure 2. The velocity achieved during these tests fluctuated between 30 and 35 ft/sec. Results are given in Table 11. Very little erosion was indicated on any of the four test specimens after 14 hr of flow. An additional 6 hr of testing on specimen 2 produced no further loss of material. Observation indicated that material lost during erosion consisted of small amounts of weak mortar adjacent to the voids in the test specimens.

Surface Treatment

33. One of the problems associated with RCC for use in mass construction is the rough edges left if forming is not used. A small mortar gun was used to determine if a properly applied shotcrete would provide an acceptable alternative to a formed surface. The mixture used was a wet process mixture in which the ratio of sand to cement was varied between 2:1 and 4:1. Only enough water was used to provide the proper gunning consistency in accordance with instructions (Coy 1974). Figure 3 shows the result of gunning several areas with different mixture proportions. Apparently, a gunned mortar would provide an acceptable surface treatment to the rough RCC either as a natural gunned finish or as a troweled or floated finish.

Freezing and Thawing Resistance

34. Results of freezing and thawing tests are shown in Table 12. Specimens from mixture 12A, which contained 5 to 6 percent total air as a result



Modified compaction test

55 blows per each of 5 layers, with 10 lb rammer and

18 inch drop. 6 inch diameter mold

Sample No.	Elev or Depth	Classification	G	LL	PL	% > No. 4	% > 3/4 in.
		Mixture of SANDY GRAVEL(GP),	2.76				
		light gray, and 12% PORTLAND	(Est.)				
		CEMENT					

Sample No.	Mix 15 - 12%	Cement		
Natural water content, percent				
Optimum water content, percent	5.1			
Max dry density, lb/cu ft	150.4			

Remarks	Project
	Area
	Boring No. - / Date
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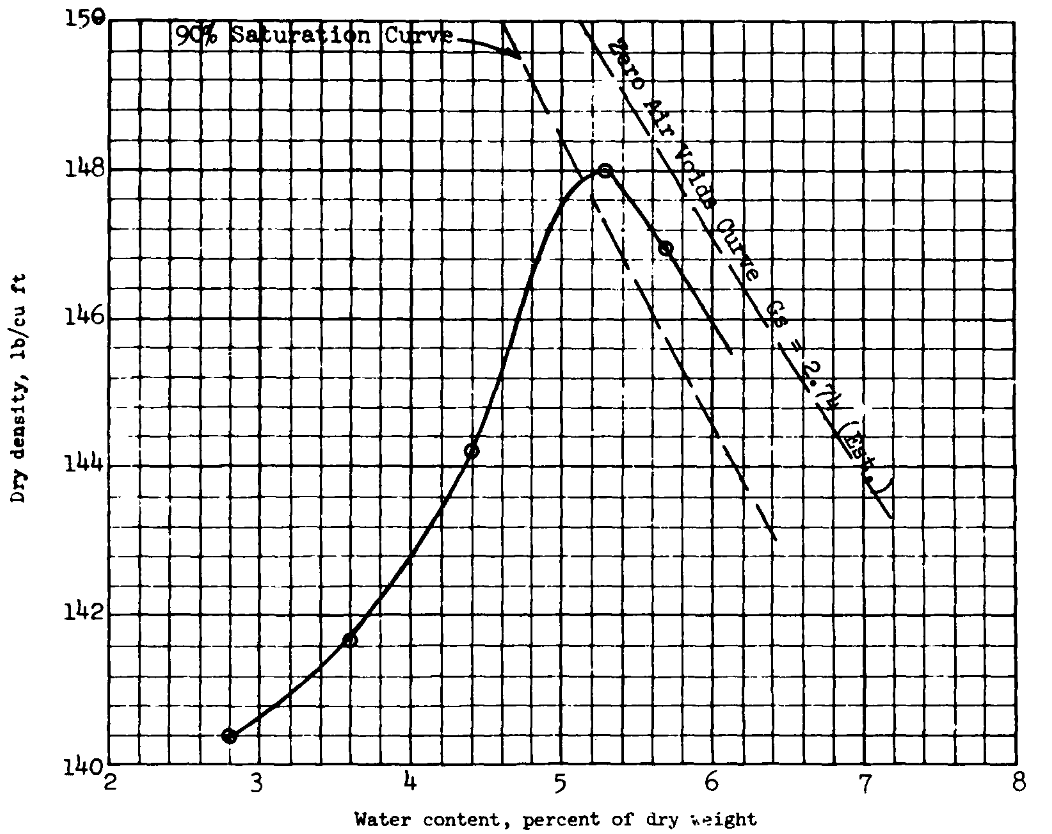
Figure 15. Compaction test report, mixture 12



Modified compaction test

55 blows per each of 5 layers, with 10 lb rammer and

18 inch drop. 6 inch diameter mold

Sample No.	Elev or Depth	Classification	G	LL	PL	% > No. 4	% > 3/4 in.
		Mixture of SANDY GRAVEL (GP),	2.74				
		light gray, and 6% PORTLAND	(Est.)				
		CEMENT					

Sample No.	Mix No. 12			
Natural water content, percent				
Optimum water content, percent	5.3			
Max dry density, lb/cu ft	148.0			

Remarks	Project
	Area
	Boring No. - / Date
	FAM

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Figure 16. Compaction test report, mixture 15

of the addition of an air-entraining admixture (AEA), were tested at two ages. At the specified test age (14 days), the relative modulus of elasticity E dropped to less than 20 percent at 11 cycles. At a test age of 90 days the test ran to 34 cycles before termination, indicating some slight improvement in resistance to freezing and thawing. Apparently the air void system obtained with the AEA was not satisfactory. Specimens from mixture 15, which contained no entrained air, sustained 69 cycles before the modulus decreased to 50 percent.

PART IV: CONCLUSIONS

35. Based on the results of this study, the following conclusions appear warranted:

- a. The curb concept is a viable method of forming and containing RCC.
- b. The degree of compaction achieved is dependent on the stiffness and the paste content of the mixture, the lift thickness, and the individual roller. An excess paste content of 5 percent appears to be needed to secure satisfactory compaction.
- c. The tensile strength of the untreated joints compared with the parent concrete increased with paste content and quality from a value of approximately 25 percent for relatively lean RCC to approximately 50 percent for richer RCC to 75 percent for conventional concrete.
- d. Erosion resistance of RCC at 35-ft/sec fluid velocity for 20 hrs of test is indicated to be very good.
- e. The moisture content which is best for rolling is approximately 1 percent less than optimum as determined by soil compaction techniques.
- f. Surface treatment by use of a mortar gun appears to be a practical method to secure smooth edges on RCC.
- g. Resistance of RCC to freezing and thawing containing up to 5 to 6 percent total air is poor, apparently due to an unsatisfactory air void system.

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Table 1

Chemical and Physical Properties of Portland Cement (RC-705)

Chemical Properties	
SiO_2, %	22.8
Al_2O_3, %	4.0
Fe_2O_3, %	4.2
CaO, %	62.8
MgO, %	3.5
SO_3, %	1.7
Ignition loss, %	0.6
Insoluble residue, %	0.26
Na_2O, %	0.12
K_2O, %	0.49
Total alkali, as Na_2O	0.44
C_3A	3.5
Physical Properties	
Fineness, air permeability, cm^2/g	3150
Compressive strength, psi (MPa)	
3 days	1630 (11)
7 days	2280 (16)

Table 2

Chemical and Physical Properties of Fly Ash (AD-474)

LABORATORY:	REPORT OF TESTS ON POZZOLAN (CRD-C 262)	REPORT NO.: WES-92F-72
Concrete Division USAE Waterways Exp.Sta. P. O. Box 631 Vicksburg, Miss. 39180		SHEET 1 OF 1 DATE: 15 May 72 * 7 Jun 72

CLASS F X N — KIND OF POZZOLAN: Fly Ash

SOURCE: Amax Fly Ash Co., Wilsonville, Ala. — BRAND:

TEST RESULTS OF THIS SAMPLE LOT XX COMPLY ☐ DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT:

CONTRACT NO.:

DISTRICT(S):

SAMPLED BY: Mr. J. L. Batson, Jr. — DATE SAMPLED: 1 May 72

CAR NO.: — BIN NO.: 3 -- 600 Tons

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 3 May 72 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Test Section — CHECKED BY:

TESTS ON COMPOSITE OF THE 200-TON SAMPLES LISTED BELOW REPRESENTING 2000 TONS OR LESS

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.5	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS							
87.8	1.4	0.1	*0.8	*90		-0.02	

TESTS ON SAMPLES REPRESENTING 200 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	AIR PERMEABILITY FINENESS SQ CM/CC (AVERAGE)	FINENESS VARIATION FROM AVERAGE OF PRECEDING 10, %	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT INCREASE IN FLOW %	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MIN 6500	MAX 20	MIN 900	MIN 0	—	MAX 5
TEST RESULTS								
1	0.4	3.9	6710	7	1285	11	2.18	4
2	0.4	3.8	6630	7	1255	12	2.18	4
3	0.4	3.7	6720	5	1260	11	2.18	3
AVERAGE	—	—	6690	—	—	—	2.18	—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED: Type II, LA

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED: Chemstone

REMARKS: Meets requirements of specification CRD-C 262 at 7 days.

*28-day tests results

W. G. MILLER
Chemist
Chief, Cement and Pozzolan Test Section

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

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Table 3

Physical Properties and Gradings of Manufactured Limestone Fine and Coarse Aggregates for Mixtures 1, 3, 6, 7, 8, and 13

Test	Fine	Size Range (No. 4 to 3/4 in.) (4.75 to 19.0 mm)	Size Range (3/4 to 1-1/2 in.) (19.0 to 38.1 mm)	Size Range (1-1/2 to 3 in.) (38.1 to 75.0 mm)	Combined Coarse Aggregate*
Physical Properties					
Bulk specific gravity, saturated surface dry	2.71	2.73	2.71	2.72	
Absorption, %	0.7	0.5	0.5	0.2	
Cumulative Percent Passing					
Size					
3 in. (75 mm)				100	100
2 in. (50 mm)			100	45	78
1-1/2 in. (38.1 mm)			92	5	60
1 in. (25.0 mm)		100	30	0	46
3/4 in. (19.0 mm)		96	1		38
1/2 in. (12.5 mm)		47	0		19
3/8 in. (9.5 mm)		19			8
No. 4 (4.75 mm)		0			0

* The three size ranges of coarse aggregates were combined in the following proportions: 40 percent, No. 4 to 3/4 in.; 20 percent, 3/4 to 1-1/2 in.; and 40 percent, 1-1/2 to 3 in.

No. 4	100	No. 50	15
No. 8	90	No. 100	7
No. 16	55	No. 200	--
No. 30	30	Fineness modulus = 3.04	

Table 4

Physical Properties and Gradings of Manufactured Limestone Fine and Coarse Aggregates for Mixtures 2, 4, 5, 9, 11, 12, 15, 16, 17, 19, and 20

Test	Fine	Size Range (No. 4 to 3/4 in.) (4.75 to 19.0 mm)	Size Range (3/4 to 1-1/2 in.) (19.0 to 38.1 mm)	Combined Coarse Aggregate*
		Physical Properties		
Bulk specific gravity saturated surface dry	2.71	2.73	2.71	
Absorption, %	0.7	0.5	0.5	
		Cumulative Percent Passing		
Sieve				
2 in. (50 mm)			100	100
1-1/2 in. (38.1 mm)			92	97
1 in. (25.0 mm)		100	30	75
3/4 in. (19.0 mm)		96	1	62
1/2 in. (12.5 mm)		47	0	31
3/8 in. (9.5 mm)		19		12
No. 4 (4.75 mm)		0		0

Note: Mixture No. 18 contained only the No. 4 to 3/4 in. size range.

* The two size ranges of coarse aggregates were combined in the following proportions: 65 percent, No. 4 to 3/4 in.; and 35 percent, 3/4 to 1-1/2 in.

No. 4	100
No. 8	90
No. 16	55
No. 30	30
No. 50	15
No. 100	7
No. 200	--

Fineness modulus = 3.04

Table 5

Physical Properties and Gradings of Natural Fine and Coarse Aggregate for Mixture 10

Test	Fine	Size Range (No. 4 to 3/4 in.) (4.75 to 38.1 mm)
Physical Properties		
Bulk specific gravity, saturated surface dry	2.64	2.56
Absorption, %	0.2	1.9
Cumulative Percent Passing		
Size		
1 in. (25 mm)		100
3/4 in. (19 mm)		100
1/2 in. (12.5 mm)		63
3/8 in. (9.5 mm)		35
No. 4 (4.75 mm)		3
No. 4	98	
No. 8	89	
No. 16	76	
No. 30	51	
No. 50	15	
No. 100	2	
No. 200	--	

Fineness modulus = 2.79

Table 6

Physical Properties and Gradings of Natural Fine and Coarse Aggregates for Mixture 14

Test	Fine	Size Range (No. 4 to 1-1/2 in.) (4.75 to 38.1 mm)	Size Range (1-1/2 to 3 in.) (38.1 to 75 mm)	Combined Coarse Aggregate*
Physical Properties				
Bulk specific gravity, saturated surface dry	2.64	2.57	2.75	
Absorption, %	0.2	1.9	0.9	
Cumulative Percent Passing				
Size				
4 in. (100 mm)			100	100
3 in. (75 mm)			87	94
2 in. (50 mm)			42	71
1-1/2 in. (38.1 mm)		100	10	55
1 in. (25 mm)		96		48
3/4 in. (19 mm)		78		39
1/2 in. (12.5 mm)		46		23
3/8 in. (9.5 mm)		29		15
No. 4 (4.75 mm)		6		3

* The two size ranges of coarse aggregates were combined in the following proportions: 50 percent, No. 4 to 1-1/2 in.; and 50 percent, 1-1/2 to 3 in.

No. 4	98
No. 8	89
No. 16	76
No. 30	51
No. 50	15
No. 100	2
No. 200	--

Fineness modulus = 2.79

Table 7

Individual Maximum Mixture Proportions

Materials	Solid Volume ft^3	Solid Volume (m^3)	Weight, Saturated Surface Dry lb/yd^3	Weight, Saturated Surface Dry (kg/m^3)
Limestone 3/4 in.				
Mixture 1				
Portland cement	1.196	0.034	235.0	139.4
Fine aggregate	6.810	0.193	1151.4	683.1
Coarse aggregate	16.670	0.472	2831.5	1679.9
Water	2.324	0.066	145.0	86.0
Total	27.000	0.765	4362.9	2588.4
Mixture 3				
Portland cement	0.598	0.017	117.5	69.7
Fly ash	0.598	0.017	81.3	48.2
Fine aggregate	7.385	0.209	1248.8	740.9
Coarse aggregate	15.695	0.445	2665.5	1581.4
Water	2.324	0.066	145.0	86.0
Air	0.400	0.011	--	--
Total	27.000	0.765	4258.1	2526.2
Mixture 6				
Portland cement	0.689	0.020	135.0	80.1
Fly ash	0.689	0.020	93.7	55.6
Fine aggregate	7.250	0.205	1226.0	727.4
Coarse aggregate	15.406	0.436	2616.8	1552.4
Water	2.566	0.073	160.1	95.0
Air	0.400	0.011	--	--
Total	27.000	0.765	4231.6	2510.5
Limestone 1-1/2 in.				
Mixture 2				
Portland cement	1.196	0.034	235.0	139.4
Fly ash	0.722	0.022	105.0	62.3
Fine aggregate	7.808	0.221	1320.3	783.3
Coarse aggregate	14.500	0.411	2463.7	1461.7
Water	2.324	0.066	145.0	86.0
Air	0.400	0.011	--	--
Total	27.000	0.765	4269.0	2532.7

(Continued)

Table 7 (Continued)

Materials	Solid Volume ft^3	Solid Volume (m^3)	Weight, Saturated Surface Dry lb/yd^3	Weight, Saturated Surface Dry (kg/m^3)
Limestone 1-1/2 in. (Continued)				
Mixture 4				
Portland cement	0.984	0.028	193.4	114.7
Fly ash	0.984	0.028	133.9	79.4
Fine aggregate	8.463	0.240	1431.1	849.0
Coarse aggregate	13.808	0.391	2346.2	1392.0
Water	2.361	0.067	147.3	87.4
Air	0.400	0.011	--	--
Total	27.000	0.765	4251.9	2522.5
Mixture 5				
Portland cement	1.196	0.034	235.0	139.4
Fly ash	0.722	0.022	105.0	62.3
Fine aggregate	7.724	0.219	1306.1	744.9
Coarse aggregate	14.344	0.406	2437.2	1445.9
Water	2.564	0.073	160.0	94.9
Air	0.400	0.011	--	--
Total	27.000	0.765	4243.3	2487.4
Limestone 3 in.				
Mixture 7				
Portland cement	0.689	0.020	135.0	80.1
Fly ash	0.689	0.020	93.7	55.6
Fine aggregate	7.250	0.205	1226.0	727.4
Coarse aggregate	15.406	0.436	2616.8	1552.4
Water	2.566	0.073	160.1	95.0
Air	0.400	0.011	--	--
Total	27.000	0.765	4231.6	2510.5
Mixture 8				
Portland cement	0.689	0.020	135.0	80.1
Fly ash	0.689	0.020	93.7	55.6
Fine aggregate	7.250	0.205	1226.0	727.4
Coarse aggregate	15.406	0.436	2616.8	1552.4
Water	2.566	0.073	160.1	95.0
Air	0.400	0.011	--	--
Total	27.000	0.765	4231.6	2510.5

(Continued)

Table 7 (Continued)

Materials	Solid Volume ft^3	Solid Volume (m^3)	Weight, Saturated Surface Dry lb/yd^3	Weight, Saturated Surface Dry (kg/m^3)
Limestone 3 in. (Continued)				
Mixture 13				
Portland cement	0.509	0.014	100.0	59.3
Fly ash	0.735	0.021	100.0	59.3
Fine aggregate	7.092	0.201	1199.3	711.5
Coarse aggregate	15.070	0.427	2559.6	1518.6
Water	2.244	0.064	140.0	83.1
Air	1.350	0.038	--	--
Total	27.000	0.765	4098.9	2431.8
Natural 3/4 in.				
Mixture 10				
Portland cement	1.196	0.034	235.0	139.4
Fly ash	0.772	0.022	105.0	62.3
Fine aggregate	8.981	0.254	1479.5	877.8
Coarse aggregate	13.472	0.382	2168.9	1286.7
Water	2.179	0.062	136.0	80.7
Air	0.400	0.011	--	--
Total	27.000	0.765	4124.4	2446.9
Natural 3 in.				
Mixture 14				
Portland cement	0.509	0.014	100.0	59.3
Fly ash	0.735	0.021	100.0	59.3
Fine aggregate	6.295	0.179	1037.0	615.2
Coarse aggregate	16.188	0.458	2686.9	1594.1
Water	1.923	0.055	120.0	71.2
Air	1.350	0.038	--	--
Total	27.000	0.765	4043.9	2399.1

(Continued)

(Sheet 3 of 5)

Table 7 (Continued)

Materials	Solid Volume ft^3	Solid Volume (m^3)	Weight, Saturated Surface Dry lb/yd^3	Weight, Saturated Surface Dry (kg/m^3)
Limestone 1-1/2 in.				
Mixture 15				
Portland cement	2.630	0.074	517.0	306.7
Fine aggregate	7.433	0.211	1256.9	745.7
Coarse aggregate	13.803	0.392	2345.3	1391.4
Water	2.734	0.077	170.6	101.2
Air	0.400	0.011	--	--
Total	27.000	0.765	4289.8	2545.0
Mixture 16				
Portland cement	0.509	0.014	100.0	59.0
Fly ash	1.470	0.042	200.0	119.0
Fine aggregate	7.277	0.206	1226.0	727.0
Coarse aggregate	14.778	0.419	2505.0	1486.0
Water	2.404	0.068	150.0	89.0
Air	0.562	0.016	--	--
Total	27.000	0.765	4181.0	2480.0
Mixture 17				
Portland cement	0.677	0.019	133.0	79.0
Fly ash	1.676	0.048	228.0	135.0
Fine aggregate	6.695	0.190	1128.0	669.0
Coarse aggregate	14.780	0.418	2505.0	1486.0
Water	2.596	0.074	162.0	96.0
Air	0.576	0.016	--	--
Total	27.000	0.765	4156.0	2465.0
Mixture 18				
Portland cement	0.763	0.022	150.0	89.0
Fly ash	1.838	0.052	250.0	148.0
Fine aggregate	7.328	0.208	1235.0	733.0
Coarse aggregate	13.610	0.385	2310.0	1370.0
Water	2.885	0.082	180.0	107.0
Air	0.576	0.016	--	--
Total	27.000	0.765	4125.0	2447.0

(Continued)

Table 7 (Concluded)

Materials	Solid Volume ft^3	Solid Volume (m^3)	Weight, Saturated Surface Dry lb/yd^3	Weight, Saturated Surface Dry (kg/m^3)
Limestone 1-1/2 in. (Continued)				
Mixture 19				
Portland cement	0.763	0.022	150.0	89.0
Fly ash	1.838	0.052	250.0	148.0
Fine aggregate	6.054	0.171	1020.0	605.0
Coarse aggregate	14.884	0.422	2490.0	1477.0
Water	2.885	0.082	180.0	107.0
Air	0.576	0.016	--	--
Total	27.000	0.765	4090.0	2426.0
Mixture 20				
Portland cement	0.763	0.022	150.0	89.0
Fly ash	1.838	0.052	250.0	148.0
Fine aggregate	6.054	0.171	1020.0	605.0
Coarse aggregate	14.884	0.422	2490.0	1477.0
Water	2.885	0.082	180.0	107.0
Air	0.576	0.016	--	--
Total	27.000	0.765	4090.0	2426.0

(Sheet 5 of 5)

Table 8

Summary of Mixture Proportions

Mixture No.	Maximum Size Aggregate in. (mm)	Cementitious Material lb/yd^3 (kg/m^3)	Fly Ash % by Volume	Water/Cement & Pozzolan by Weight	Sand/Aggregate % by Volume	Excess Paste %	Consolidated Time sec	Lift Depth in. (mm)	Remarks
1	3 (76)	235 (139)	0	0.62	29	2.1	90	--	Not rolled; mixture from previous work. Did not appear to consolidate--roller could not roll over large rock
2	1.5 (38)	340 (202)	39	0.43	35	3.5	90	8 (200)	Did not consolidate
							--	6 (150)	Did not consolidate well
							90	4 (100)	Consolidated (over previous lifts)
3	3 (76)	200 (119)	50	0.73	32	0	90	None	Too harsh for roller
4	1.5 (38)	327 (193)	50	0.45	38	1.8	60	None	Too harsh for 10-in. lifts
5	1.5 (38)	340 (202)	39	0.47	35	5.0	40	6 (150)	Rolled on 2-hr-old concrete
							45	8 (200)	Over fresh concrete, rolled better
							45	6 (150)	Over 2-hr concrete--OK
							45	10 (250)	Over 1-hr concrete--OK
6	3 (76)	229 (136)	50	0.70	32	3.2	20		Consolidated well; a little too wet
							35		"Rubbery," good consolidation
							40		Appeared to be approaching dry limit
7	3 (76)	229 (136)	50	0.70	32	3.2	20		Used 20% mortar sand--rolled well
8	3 (76)	229 (136)	50	0.70	32	3.2	60		Over 4-hr concrete--too dry
							20		Over fresh concrete; rolled well
							25		3-in. rock--rolled well
9	1.5 (38)	340 (202)	39	0.48	35	5.0	35	8 (200)	Looked good; rolled well
							25	6 (150)	"Rubbery," rolled well
							35	4 (100)	Mixture 5 with slight increase in water
10	0.75 (19)	340 (202)	39	0.40	40	1.6	50	10 (250)	Natural aggregates; rolled well, sprang back after rolling
								6 (150)	
11	1.5 (38)	300 (178)	74	0.50	37	2.8	20	10 (250)	Looked good; rolled well
							25	10 (250)	Used 20% mortar sand, rolled well
12	1.5 (38)	250 (148)	68	0.60	38	0	20	10 (250)	Rolled well
12A	1.5 (38)	250 (148)	68	0.60	38	0	30	10 (250)	Rolled well; contained 5 to 6% air

(Continued)

Table 8 (Concluded)

Mixture No.	Maximum Size Aggregate in. (mm)	Cementitious Material lb/yd^3 (kg/m^3)	Fly Ash % by Volume	Water/Cement & Pozzolan by Weight	Sand/Aggregate % by Volume	Excess Paste %	Consolidated Time sec	Lift Depth in. (mm)	Remarks
13	3 (76)	200 (119)	59	0.70	32	0	15 18	10 (250) 10 (250)	Roller moved large rock OK, but mix too wet--segregated
14	3 (76)	200 (119)	59	0.60	28	3.5	20 25	10 (250) 10 (250)	Natural aggregates--produced very smooth rolled surface
15	1.5 (38)	517 (305)	0	0.33	35	3.0	20 25	6 (150) 10 (250)	Paving mix--rolled well Reported in Burns (1976)
16	1.5 (38)	300 (178)	74	0.50	33	2.0	25 20	10 (250) 6 (150)	Curb tests--voids noted in underside of rolled area
17	1.5 (38)	361 (213)	71	0.45	31	5.0	25	8 (200)	Few voids noted underside
18	0.75 (19)	400 (238)	61	0.45	35	8.0	21 25	8 (200) 6 (150)	Very rich mixture, small aggregate; result, sticky
19	1.5 (38)	400 (238)	61	0.45	29	10.0	1*	6 (150)	Conventional concrete
20	1.5 (38)	400 (238)	61	0.45	29	10.0	8*	6 (150)	Mixture 19 with high range water-reducing admixture

* Slump, in.

Table 9

Tests of Joints (Mixture 9)

Specimen No.	Point Load Tensile Strength psi (kpa)
Cold joint (24 hr)	
1	175 (1210)
2	115 (790)
3	175 (1210)
4	175 (1210)
5	185 (1280)
6	165 (1140)
Avg	165 (1140)
Fresh joint (1 hr)	
1	230 (1590)
2	275 (1900)
3	350 (2410)
4	260 (1790)
5	255 (1760)
6	255 (1760)
Avg	270 (1860)
Parent concrete	
1	340 (2340)
2	295 (2030)
3	320 (2210)
4	325 (2240)
5	285 (1970)
6	295 (2030)
Avg	310 (2140)

Table 10

Tensile Strength Tests of Concrete and Joints

Mixture 16, Lean RCC		Mixture 18, Richer RCC		Mixture 19, Conventional		Mixture 20, Flowing	
Concrete	Joint	Concrete	Joint	Concrete	Joint	Concrete	Joint
Point Load, psi							
195	60	295	--	330	205	280	150
225	--	315	85	330	315	270	125
205	--	295	140	320	185	275	165
275	90	305	75	285	200	305	140
250	35	260	110	265	205	285	160
225	60	300	155	295	230	260	110
190	55	260	145				
235	--	265	55				
250	70	280	170				
220	--	265	210				
175	50	285	180				
260	--	290	60				
Avg 225 (12)*	60 (7)	Avg 285 (12)	125 (11)	Avg 305 (6)	225 (6)	Avg 280 (6)	140 (6)
Joint/Concrete 27%		Joint/Concrete 44%		Joint/Concrete 74%		Joint/Concrete 50%	
Point Load, kPa							
1340	410	2030	--	2280	1410	1930	1030
1550	--	2170	590	2280	2170	1860	860
1410	--	2030	970	2210	1280	1900	1140
1900	620	2100	520	1970	1380	2100	970
1720	240	1790	760	1830	1410	1970	1100
1550	410	2070	1070	2030	1590	1790	760
1310	380	1790	1000				
1620	--	1830	380				
1720	480	1930	1170				
1520	--	1830	1450				
1210	340	1970	1240				
1790	--	2000	410				
Avg 1550 (12)	410 (7)	Avg 1970 (12)	870 (11)	Avg 2100 (6)	1540 (6)	Avg 1930 (6)	970 (6)
Joint/Concrete 27%		Joint/Concrete 44%		Joint/Concrete 74%		Joint/Concrete 50%	

* Numbers in parentheses are the number of tests included in the average.

Table 11

Erosion Tests

Specimen No.	Surface	Hours of Test: Individual	Hours of Test: Cumulative	Erosion/lb*: Individual	Erosion/lb*: Cumulative
1	Cast	7	7	0.05	0.05
		7	14	0.01	0.06
2	Cast	7	7	0.10	0.10
		7	14	0.05	0.15
		6	20	0.00	0.15
3	Rolled (smooth)	5	5	0.00	0.00
		3	8	0.00	0.00
		6	14	0.00	0.00
4	Rolled (rough)	3	3	0.04	0.04
		3	6	0.01	0.05
		4	10	0.00	0.05
		4	14	0.00	0.05

* On a 1-sq-ft surface.

Table 12

Results of Freezing and Thawing Tests

Mixture No.	Test Age days	Specimen No.	Relative Modulus of Elasticity E at Cycles Shown: 0	11	23	34	69
12A	14	1	100	7			
		2	↓	17			
		3	↓	20			
		4	↓	19			
		5	↓	13			
		6	↓	18			
12A	90	7	↓	--	30	11	
		8	↓	--	32	13	
		9	↓	--	31	12	
		10	↓	--	27	8	
		11	↓	--	31	12	
		12	↓	--	27	9	
15	14	13	↓	91	--	76	50
		14	↓	89	--	78	48
		15	↓	91	--	75	44
		16	↓	91	--	79	50
		17	↓	91	--	76	46
		18	↓	86	--	60	32

END

FILMED

1-85

DTIC